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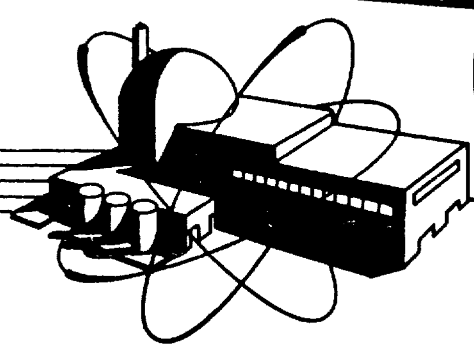
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

62 NOX 1-2

U.S. ARMY ENGINEER REACTORS GROUP

NUCLEAR POWER FIELD OFFICE



Operations Support Branch

Engineer Reactors Group
Corps of Engineers
United States Army

Report OSB 15

Revision 1

Final Report on Investigation of SM-1 Control Rod Seal Failure

Prepared by:
Engineering Support Section

Distributed by:
Operations Support Branch
Nuclear Power Field Office
Fort Belvoir, Va.

Report OSB 15

Revision No. 1

Final Report on Investigation of SM-1 Control Rod Seal Failure

G. W. KNIGHTON
Engineering Support Section
Operations Support Branch

Approved by:

LEO J. MISENHEIMER
Chief, Operations Support Branch
Nuclear Power Field Office

18 July 1961

PREFACE

As a result of the preliminary investigation[1] of the SM-1 Control Rod Seal failure on 26 March 1961, Job #63 under Contract DA-44-192-ENG-17 was prepared to cover a complete physical, metallurgical, and chemical investigation of the shafts. This investigation is to ascertain the probable cause of failure and any corrective action which may be taken for longer life of the seals. The following report prepared by Alco Products states in detail the requirements of the job and the results of the investigation.

[1]Preliminary Investigation of SM-1 Control Rod Seal Failure Report 15, Engineers Support Section, Operations Support Br.

AP NOTE 362

Copy No. ______

JOB 63 - INSPECTION OF SM-1 CONTROL ROD SEAL COMPONENTS

By

R. A. Chittum R. M. Saccocio

H. R. Clayton C. A. Bergmann

Approved By:

J. P. Tully, Leader, Mechanical Design Group

Issued: June 16, 1961

Contract No. DA-44-192-ENG-17
with U. S. Army Engineer Research and
Development Laboratories, Fort Belvoir, Virginia

ALCO PRODUCTS, INC.
Nuclear Power Engineering Department
Post Office Box 414
Schenectady 1, N. Y.

ALCO LEGAL NOTICE

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1.0 SUMMARY

A laboratory test has been completed to check leakage rates of a control rod drive seal assembly (shaft, seal rings and diaphragms) which had been in operation in the SM-1 since its original startup. These seal components were removed from the reactor around April 1961 because of an increase in leakage above their original rates.

The testing, performed at simulated reactor operating pressure (1200 psi) and room temperature, was conducted in two phases. The difference of each phase being only the method of seal assembly. The first phase consisted of determining the leakage rate with the seal correctly assembled i.e., per assembly drawing C 9-11-1002; the second phase consisted of determining the seal leakage rate with it assembled as it had been during reactor operation i.e., the first diaphragm and seal ring turned around on the seal shaft.

Tested cold (70°F) seal leakage rates were as follows:

Phase I Seal correctly assembled

Drive motor not running - 8.82 #/Hr (1.06 GPH)

Drive motor running -14.92 #/Hr (1.79 GPH)

Phase II Seal incorrectly assembled

Drive motor not running - 6.48 #/Hr (0.78 GPH)

Drive motor running - 9.68 #/Hr (1.16 GPH)

When the above values are corrected to an assumed seal leakage water temperature of 170°F (thermal expansion and corresponding clearance changes neglected) the leakage rates become the following "ball park" figures:

Phase I Seal correctly assembled.

Drive motor not running - 22.7 #/Hr (2.79 GPH)

Drive motor running - 38.5 #/Hr (4.73 GPH)

Phase II Seal incorrectly assembled

Drive motor not running - 16.7 #/Hr (2.05 GPH)

Drive motor running - 25.0 #/Hr (3.07 GPH)

The test indicated that deposited crud was not the major cause for the high leakage rates of the seals.

No measurable wear was found when the components were measured. Thus, the determination of the extent of pitting, erosion and wear to the seal components had to be made by the use of micrographs.

Micrographical examination of the chromium plate on a seal shaft removed from the SM-1 showed considerable pitting, corrosion and erosion under and adjacent to some of the stellite ring areas. For comparative purposes, a parallel chromeplate quality investigation was made on a similar component recently manufactured by Alco for another reactor. The comparison showed the SM-1 chromium deposit to be of somewhat inferior quality and indications are that inadequate preplating cleaning had been performed. Based upon available evidence from this examination, the most likely cause of removal of the chromium plate was the poor quality plating and inadequate preplate cleaning which resulted in non-metallic inclusions in the material.

The results of the chemical and radiochemical analysis of the material removed from the seal components indicate clearly that the material is not typical primary coolant

water crud. The material appears to be corrosion and wear products of the chromium plate mixed with the coolant water crud.

2.0 INTRODUCTION

Increasing leakage from some of the water seals at the SM-1 indicated the need for an inspection of the seal components to determine the cause. An OSB Job Sheet for job number 63 under the ENG-17 contract was written, requesting an investigation of the seal components, ALCO in Schenectady was requested to recommend a work outline for the seal components' inspection. Two seal shafts and one set of rings and diaphragms were sent to ALCO for investigation.

As requested, the following work outline was recommended and carried out:

1. Remove and analyze crud and clean-up components to remove surface contamination by scrubbing.
2. Make complete dimensional check of the components compare with drawing dimensions.
3. Examine shafts, rings and diaphragms visually and under magnification and try to identify character of wear and for erosion and corrosion.
4. Section shafts and make metallographic examination.
5. Assemble seal shaft #2 with the rings and diaphragms in a laboratory seal housing and check for leakage at ambient temperature and 1200 psi.

3.0 CRUD ANALYSIS

The seal rings, diaphragms and lantern ring were descaled ultrasonically two times in demineralized water, each time for about one-half hour. After the first cleaning, 21.9 mgs (ignited weight) of material was removed. This material was ignited and brought into solution with a HNO_3 - HF - $HClO_4$ mixture. The solution was analyzed chemically for iron, cobalt, nickel, chromium and manganese. The solution was also analyzed radiochemically for Co^{58} and Co^{60}. In the second descaling, 7.3 mgs (dry weight) of material was removed. This material was analyzed for carbon content.

The first batch of descaled material removed had a radiation level of 6 mr/hr and the second batch of descaled material had a level of 0.7 mr/hr. The radiation level of the components indicates that most of the activity was induced in the material by the neutron flux, rather than the radioactive material deposited on them.

The seal shafts were not descaled since they were relatively clean and it was felt that a large enough sample of crud could not be obtained for chemical analysis.

The results of chemical analyses of the ignited material are listed below. The average analysis of coolant ignited crud is also given for comparison.

Element	Per Cent	
	Crud From Seal Rings, Diaphragms and Lantern Ring	Average Analysis of Primary Coolant Crud
Iron	20.5	50.6
Chromium	10.5	0.27
Nickel	5.0	5.20
Cobalt	3.0	0.20
Manganese	Not Detected	0.40

The carbon content of the dried material was found to be 14.1 per cent. Gamma spectrometer scans of smear samples showed the activity consisted mainly of Co^{58} and Co^{60}. The specific activity of Co^{60} was 9.1×10^5 dpm/mg material removed and that of Co^{58} was 1.6×10^5 dpm/mg material removed. Normal crud specific activity runs around 10-20 times these values. In addition, the nuclide ratio of Co^{58}/Co^{60} for this sample is 0.18, while normal crud is around 0.5. Therefore, the low specific activity of the cobalt nuclides and their low ratio indicate older primary crud has been mixed with material different from typical crud.

The unusually high chemical percentages of chromium and cobalt, and lower percentages of iron in the material removed, indicates the presence of material arising locally. As oxides, 55.3% of the material removed has been accounted for. No additional analysis for other elements were made.

In summary, the results of the chemical and radiochemical analysis of material removed from the components of the water seal assembly, indicate clearly that the material is not typical

primary coolant water crud. The material appears to be wear and erosion products of the seal shaft mixed with the coolant crud.

4.0 SEAL LEAKAGE TEST

Prior to assembly of the seal components for the test, the rings and diaphragms were ultrasonically descaled, the shafts were washed and all of the subject items measured. From sketches 1 and 2, it can be seen that there was no measurable wear.

Since pitting and marking on the shafts were visible to the naked eye, the surface condition was known to have deteriorated. The extent of deterioration would be determined later by micrographical examination. (See section 5.0)

The rings and diaphragms were assembled with shaft #2 in a laboratory seal housing. Special care was taken to make sure the rings and diaphragms were assembled so that they coincided with the wear marks on the seal shaft. The seal assembly, with the seal ring adjacent to the seal end plate omitted, was bolted to the SM-1 control rod drive test loop. A drive motor was directly coupled to the seal assembly and the coolant water inlet connector was plugged.

The test rig was filled with tap water at ambient temperature and pressurized to 1200 psi. The leakage water from the seal was collected for one hour with weighings taking place every fifteen minutes. Next the seal shaft was rotated in both directions and the seal leakage again collected for one hour.

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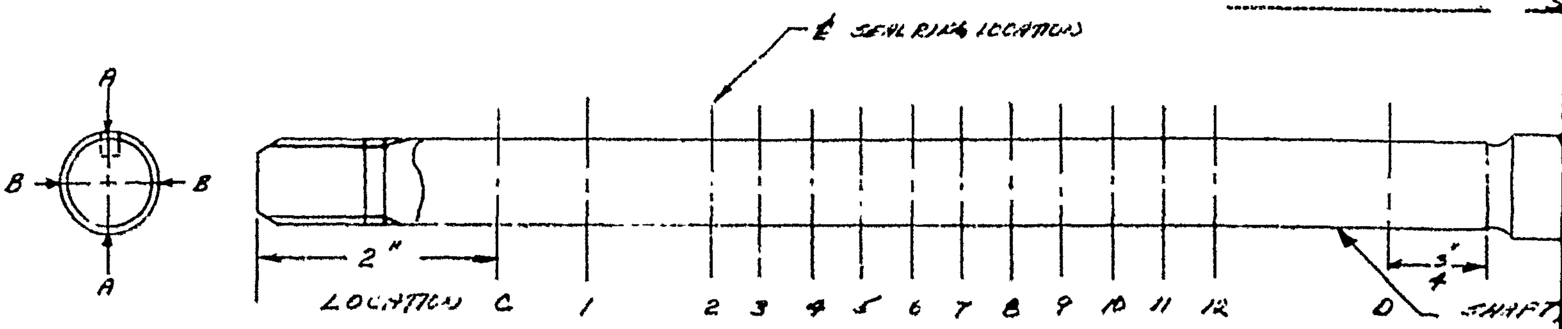

NOMINAL SHAFT DIAMETER — .6252" / .6250"

MEASUREMENTS

	* SHAFT #1		* SHAFT #2	
LOCATION	DIA "A-A"	DIA "B-B"	DIA "A-A"	DIA "B-B"
1	0.6253	0.6252	0.6252	0.6252
2	0.6252	0.6255	0.6255	0.6252
3	0.6254	0.6252	0.6252	0.6252
4	0.6252	0.6252	0.6252	0.6252
5	0.6252	0.6251	0.6252	0.6253
6	0.6255	0.6252	0.6253	0.6252
7	0.6253	0.6252	0.6252	0.6252
8	0.6253	0.6252	0.6254	0.6255
9	0.6253	0.6252	0.6252	0.6254
10	0.6253	0.6252	0.6253	0.6253
11	0.6252	0.6251	0.6253	0.6255
12	0.6254	0.6252	0.6252	0.6254
C	0.6253	0.6253	0.6253	0.6253
D	0.6253	0.6252	0.6253	0.6253

* SHAFT
WAS MAR
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1

ALCO PRODUCTS INC. SKETCH #1

BY Seccocio DATE 5/18/61 SUBJECT Control Rod Drive Water Seal Measurements SM-1 SHEET NO. ___ OF ___

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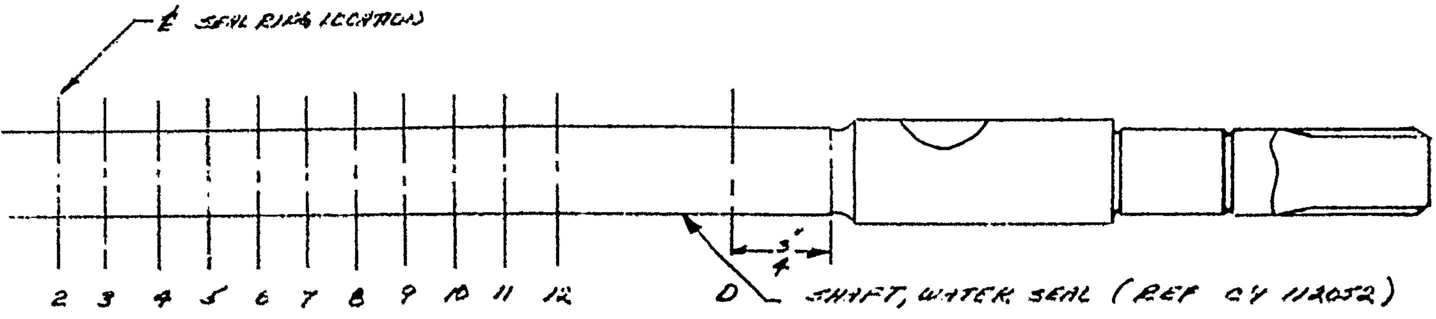


NOMINAL SHAFT DIAMETER — .6252" / .6250"

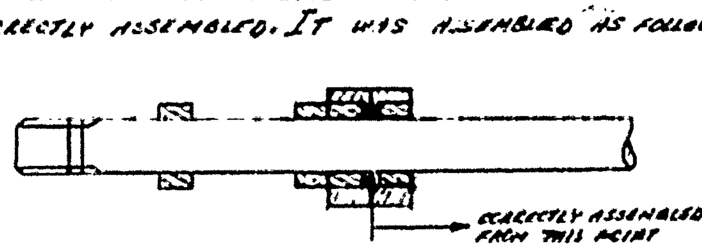
MEASUREMENTS

	* SHAFT #1		* SHAFT #2	
LOCATION	DIA A-A	DIA B-B	DIA A-A	DIA B-B
1	0.6253	0.6252	0.6252	0.6252
2	0.6252	0.6255	0.6255	0.6252
3	0.6254	0.6252	0.6252	0.6252
4	0.6252	0.6252	0.6252	0.6252
5	0.6252	0.6251	0.6252	0.6253
6	0.6255	0.6252	0.6253	0.6252
7	0.6253	0.6252	0.6252	0.6252
8	0.6253	0.6252	0.6254	0.6255
9	0.6253	0.6252	0.6252	0.6254
10	0.6253	0.6252	0.6253	0.6253
11	0.6252	0.6251	0.6253	0.6255
12	0.6254	0.6258	0.6252	0.6254
C	0.6253	0.6253	0.6253	0.6253
D	0.6253	0.6252	0.6253	0.6253

NOTES:

* SHAFT #1 HAD NO IDENTIFYING MARKS, SHAFT #2 WAS MARKED "2".

① DUE TO THE ARRANGEMENT OF THE WEAR MARKS ON SHAFT #2 IT WAS CLEARLY EVIDENT THAT THE SEAL WAS INCORRECTLY ASSEMBLED. IT WAS ASSEMBLED AS FOLLOWS:



② ALTHOUGH THE MEASUREMENTS INDICATE LITTLE OR NO WEAR, EXAMINATION OF THE SHAFTS UNDER A MICROSCOPE SHOWED THAT THE CHROME PLATING HAD BECOME PITTED AT MOST OF THE SEAL RING MATING SURFACES. AT MANY PLACES THE DEGREE OF PITTING WAS SUCH THAT THE BASE METAL WAS VISIBLE

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2

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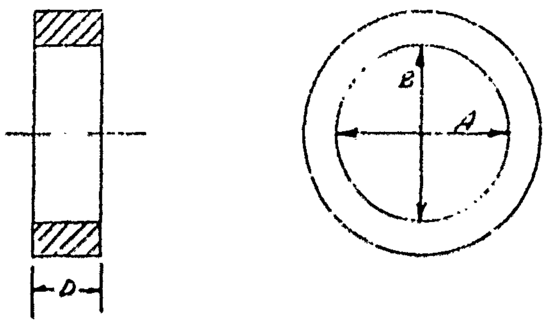
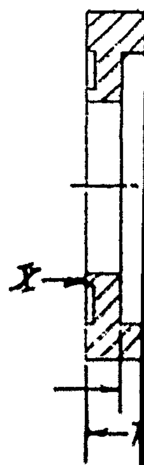
SEAL RING



NOTE: "A", "B", "D", "T" & "P" DIMENSIONS ARE TO BE TAKEN AT RANDOM WITH NO REPEATED POINT ORIENTATION FROM ONE RING OR DIAPHRAGM TO ANOTHER



MEASUREMENTS

ADDITIONAL MEASUREMENTS

0.6256, 0.6249 (RING NO. 2)

RING NO.	DIA "A"	DIA "B"	THICK. D
1	0.6253	0.6252	0.2490
2	0.6250	0.6255	0.2484
3	0.6255	0.6248	0.2487
4	0.6259	0.6257	0.2484
5	0.6251	0.6254	0.2483
6	0.6252	0.6253	0.2491
7	0.6257	0.6256	0.2488
8	0.6255	0.6252	0.2486
9	0.6253	0.6255	0.2494
10	0.6255	0.6256	0.2483
11	0.6256	0.6258	0.2488
12	0.6257	0.6253	0.2486

NOMINAL DIMENSIONS

DIA "A" } DIA "B"	.6255" / .6257"
THICK "D"	.2490 / .2488

NOTES:

* DEPTH "P" MEASUREMENTS ARE ESTIMATED BECAUSE DEPTH GAUGE READ ONLY TO .001 IN.

① THERE WAS A CONSIDERABLE AMOUNT OF WEAR ON THE SIDE OF THE RINGS THAT MATES WITH THE SURFACE MARKED X IN THE ABOVE DIAPHRAGM SKETCH. THE WEAR ON THE RINGS CONFORMED TO THE SHAPE OF SURFACE X. DUE TO THE ROUNDED ENDS ON THE MICROMETER ANVIL THE DEPTH OF THE WEAR WAS UNABLE TO BE DETERMINED. HOWEVER IT IS ESTIMATED THAT THE DEPTH WAS ONE TO TWO THOUSANDTHS OF AN INCH.

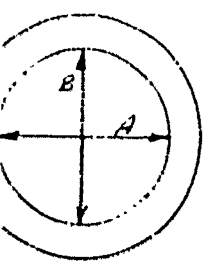
② ALL PARTS WERE ULTRASONICALLY CLEANED PRIOR TO ANY MEASUREMENTS AND NO SIGNIFICANT TRACE OF CRUD WAS EVIDENT

RMS 5/10/61

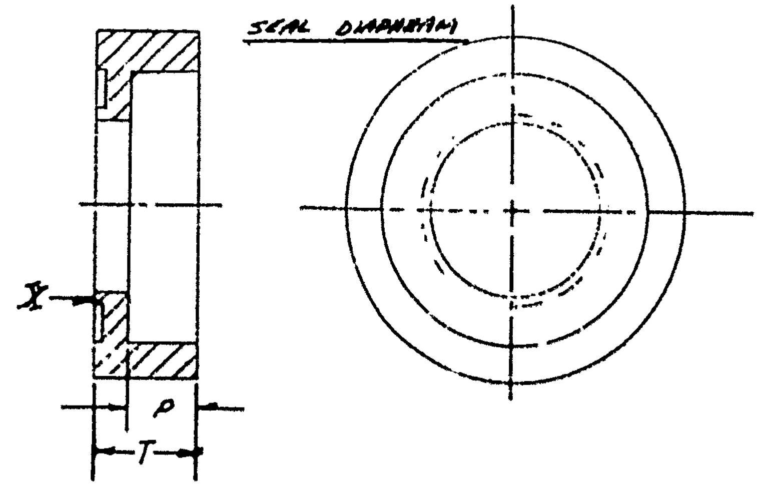
1

ALCO PRODUCTS INC.

BY Saccoccio DATE 5/10/61 SUBJECT CONTROL ROD DRIVE WATER SEAL MEASUREMENTS – SA-1 SKETCH # 2
CHKD. BY ______ DATE ______ SHEET NO. ____ OF ____
JOB NO. ______



NOTE: "A", "B", "D", "T" & "P" DIMENSIONS ARE TO BE TAKEN AT RANDOM WITH NO REPEATED POINT ORIENTATION FROM ONE RING OR DIAPHRAM TO ANOTHER



...MENTS

...'B'	THICK. D
...2	0.2490
...5	0.2484
...8	0.2487
...57	0.2484
...54	0.2483
...3	0.2491
...6	0.2488
...8	0.2486
...5	0.2494
...6	0.2483
...8	0.2488
...3	0.2486

NOTES:

* DEPTH "P" MEASUREMENTS ARE ESTIMATED BECAUSE DEPTH GAUGE READ ONLY TO .001 IN.

① THERE WAS A CONSIDERABLE AMOUNT OF WEAR ON THE SIDE OF THE RINGS THAT MATES WITH THE SURFACE MARKED X IN THE ABOVE DIAPHRAM SKETCH. THE WEAR ON THE RINGS CONFORMED TO THE SHAPE OF SURFACE X. DUE TO THE ROUNDED ENDS ON THE MICROMETER ANVIL THE DEPTH OF THE WEAR WAS UNABLE TO BE DETERMINED. HOWEVER IT IS ESTIMATED THAT THE DEPTH WAS ONE TO TWO THOUSANDTHS OF AN INCH.

② ALL PARTS WERE ULTRASONICALLY CLEANED PRIOR TO ANY MEASUREMENTS AND NO SIGNIFICANT TRACE OF CRUD WAS EVIDENT

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MEASUREMENTS

DIAPHRAM NO	THICK "T"	*DEPTH P
1	0.3747	0.2502
2	0.3746	0.2510
3	0.3747	0.2506
4	0.3747	0.2503
5	0.3748	0.2510
6	0.3747	0.2507
7	0.3744	0.2507
8	0.3748	0.2502
9	0.3750	0.2510
10	0.3747	0.2504

NOMINAL DIMENSIONS

THICK. "T" $\frac{.3750"}{.3745"}$

DEPTH "P" $\frac{.2505"}{.2500"}$

2

The data recorded from this phase of testing is as follows:

Drive Not Running		Drive Running	
Time	Seal Leakage (lbs)	Time	Seal Leakage (lbs)
1436	Started Test	0830	Started Test
1451	2.42	0845	3.60
1506	1.53	0900	3.74
1521	3.02	0915	3.78
1536	1.98	0930	3.76
1551	2.26	0945	3.70
1606	2.06		
Average - 8.82 lbs/hr		Average - 14.92 lbs/hr	

The test rig was depressurized, the seal assembly removed and disassembled. On reassembling the seal for the second phase of testing, the first ring and diaphragm set on the reactor side of the seal were reversed in order to match the assembly that was used at SM-1. The seal was connected to the test rig and drive motor and the above test was repeated.

Data recorded during this second and final phase of testing is as follows:

Drive Not Running		Drive Running	
Time	Seal Leakage (lbs)	Time	Seal Leakage (lbs)
1355	Started Test	1510	Started Test
1410	1.68	1525	2.23
1425	1.63	1540	2.55
1440	1.62	1555	2.44
1455	1.50	1610	2.44
1510	1.66	1625	2.45
Average - 6.48 lbs/hr		Average - 9.68 lbs/hr	

In conclusion, the following facts have been established:

(1) The data taken indicates that the increased leakage of the SM-1 seal assemblies was not due to the crud deposited during operation, though it might have been a minor contributor.

(2) The incorrect assembly of the first ring and diaphragm seemed to have no significant effect on the leakage rate.

(3) The increase in the leakage rate due to the loss of lapped surfaces could not be measured, but was assumed to be negligible in comparison to the effect caused by the chrome plate deterioration.

5.0 EXAMINATION OF SEAL COMPONENTS

A thorough examination of the two seal shafts, rings and diaphragms was performed. This study included macroscopic and microscopic investigation of the subject items.

5.1 K-MONEL DIAPHRAGMS

The diaphragms showed little damage beyond slight polishing of the wear surface with the highest unit loading. This surface is the narrow lip contacting the seal ring at the downstream side of the seal ring.

5.2 STELLITE SEAL RINGS

The rings showed only a very light wear pattern at the interface where the rings contact the diaphragm lips.

5.3 CHROMIUM PLATED 17-4 PH STEEL SEAL SHAFTS

5.3.1 General

The deterioration on both shafts was generally confined to the interfaces between the shaft and rings. The condition to the plating varied from very light pitting to complete removal in one small area. The damage did not extend into the 17-4 PH steel. There was no evidence of general flaking or spalling of the chromium.

5.3.2 Discussion

A pitted, corroded and eroded area on seal shaft #1 is shown at 10 diameters magnification in Figure 1. Flow direction is from right to left. The large pit, approximately 0.030" in diameter in the upper right of the photograph is an area of complete chromium removal down to the surface of the shaft.

A longitudinal micro section through the center of this pit is shown in Figure 2 at 100 diameters.

The left, or downstream edge of this pit is shown in Figure 3 at 1000 diameters. Careful examination of the exposed 17-4 PH surface material revealed no evidence of attack.

A longitudinal micro-section through a typically pitted or eroded area under a seal ring is shown in Figure 4 at 1000 diameters magnification. The chromium thickness at the lowest point is .0033". The thickness in unaffected areas is .005".

The presence of large non-metallic particles in the chromium plate is also shown in Figure 4. Similar particles at the surface could easily have been dislodged to form a site for accelerated pitting-type corrosion which ultimately led to the pit noted in Figure 1. This same type of chromium plate failure has been reported in a failure analysis study made by The Electrolizing Company * of over 650 chromium plated components.

The presence of numerous small sized particles as shown in Figure 4 could have contributed significantly to the corrosion and/or erosion exhibited in areas under seal rings. As reported by The Electrolizing Company,* grinding after chromium plating significantly increased the incidence of such particles exposed at the surface of the chromium plate.

* Note:- The Electrolizing Company, "Parts Failures Caused by Unsuspected and Widespread Presence of Non-Metallic Abrasive Contaminants on Bearing Surfaces", Research Report, 1961.

The non-metallic film or layer between the 17-4 PH base metal and the chromium deposit is clearly visible in Figures 3 and 4. This layer is approximately .00005" thick. Under polarized light, this layer seems to be the same material present in the chromium deposit in the form of vertical dikes and irregular inclusions.

The deposit itself is definitely sedimentary. Three distinctly different layers are identified under polarized light, and may be seen on the bright field, Figure 5 at 950 diameters magnification, showing a relatively un-worn area.

The chromium seal surface inherent crack pattern is shown at 250 diameters magnification in Figure 6. This pattern, showing 330 cracks per inch by lineal analysis, is indicative of chromium plate having high residual as-plated tensile stresses and low fatigue strength.* Micro hardness readings of the plate averaged 900 Knoop with a 100 gram load, which is equivalent to Rockwell C-62.

A satisfactory chromium plate is shown in Figure 7 at 250 diameters magnification. The crack pattern is 2750 cracks per inch, with a 100 gram Knoop hardness average of 1075 or equivalent Rockwell C-66. Total absence of the non-metallic intermediate layer is shown on Fig. 8, a longitudinal micro section photographed at 1000 diameters. This plating was performed under closely controlled conditions on a replacement seal shaft manufactured by Alco for The Elk River Reactor.

* Note:- Stareck, Jesse E., "Development of a Substitute or Improvement of Chromium Electrodeposits", WADC Technical Report 53-271, Part 2, December 1954.

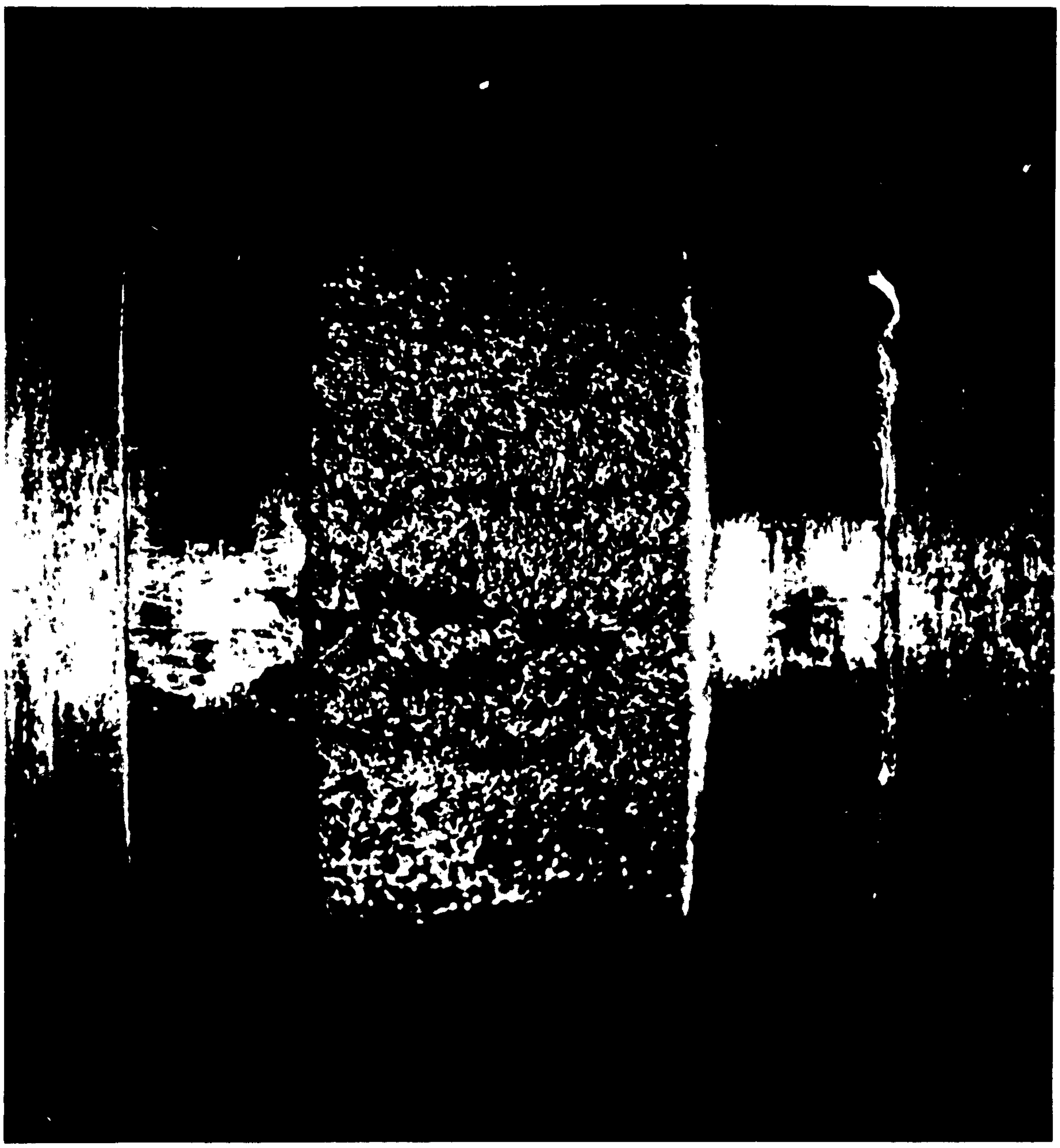

Figure 1 - Photograph of Drive Shaft #1 Showing Badly Corroded and/or Eroded Areas (10X)

Figure 2 - Longitudinal Section Through Large Pit Shown in Upper Right of Figure 1. (100X)

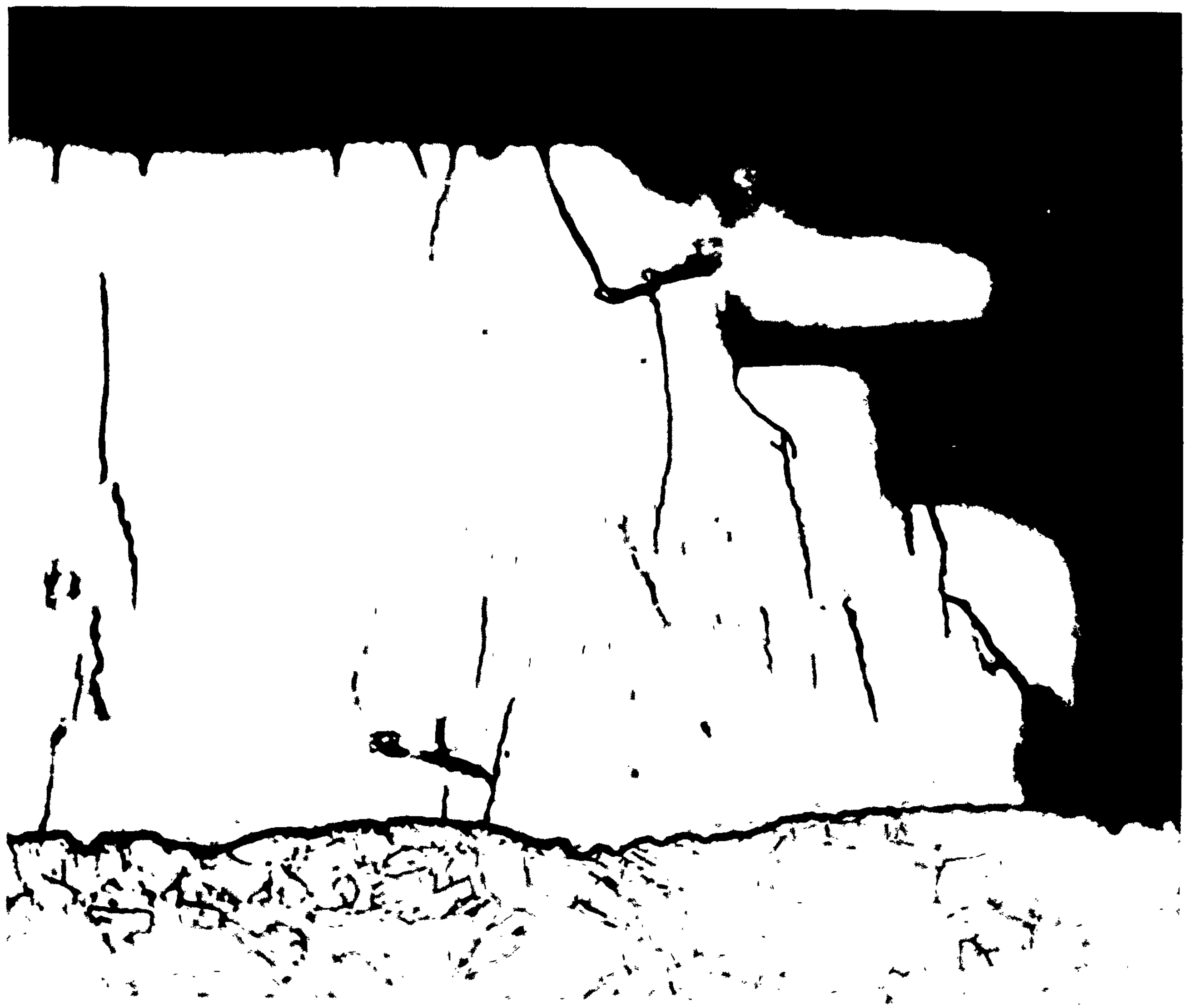

Figure 3 - The Left or Downstream Side of Pit Shown in Figure 2
at 1000 Diameters. (1000X)

Figure 4 - A Longitudinal Section Through Area Under Seal Shaft at 1000 Diameters. (1000X). At This Point .0013 Inch of Chromium Had Been Removed.

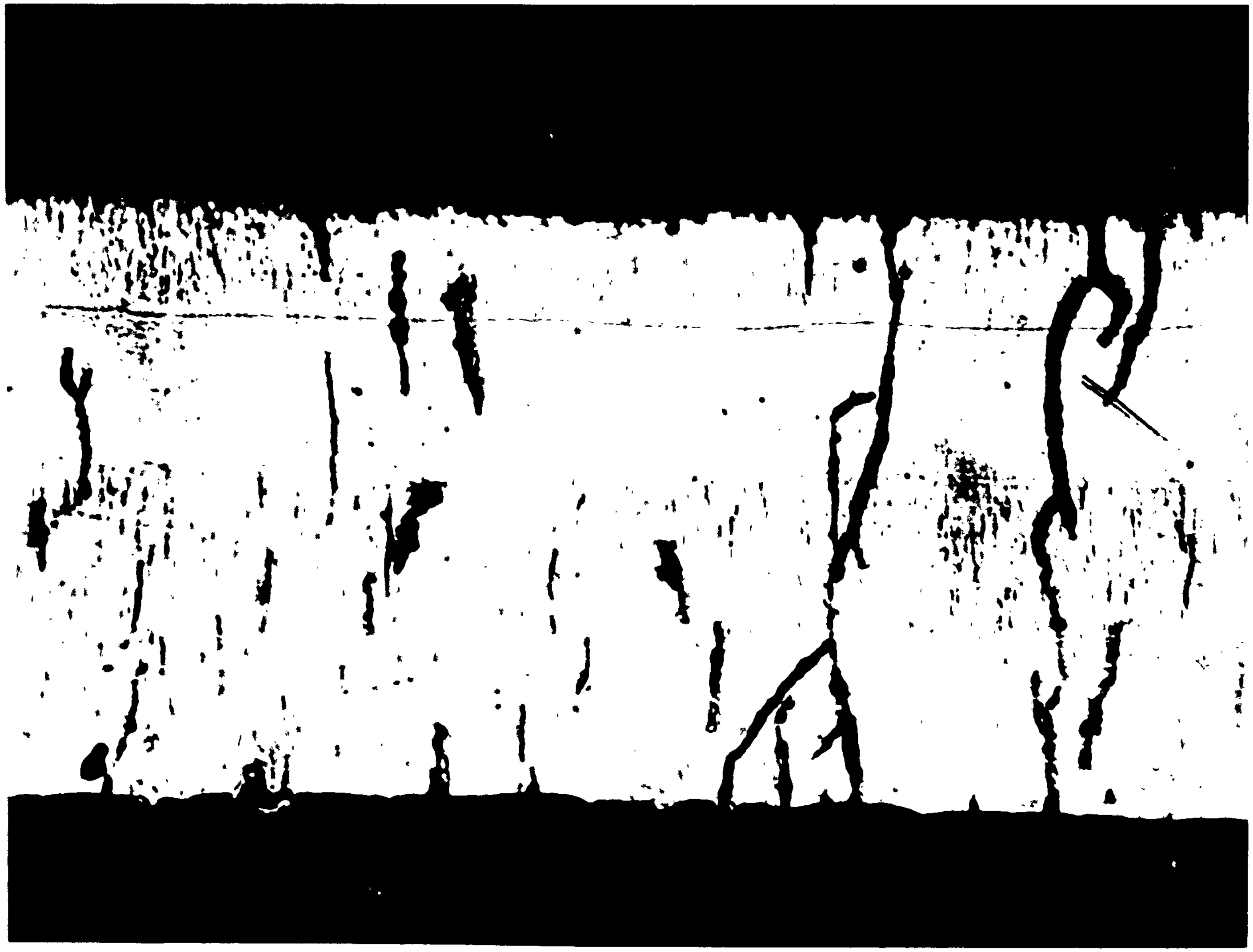

Figure 5 - A Longitudinal Section Through a Relatively Unworn Area of Chromium Plate. (950X)

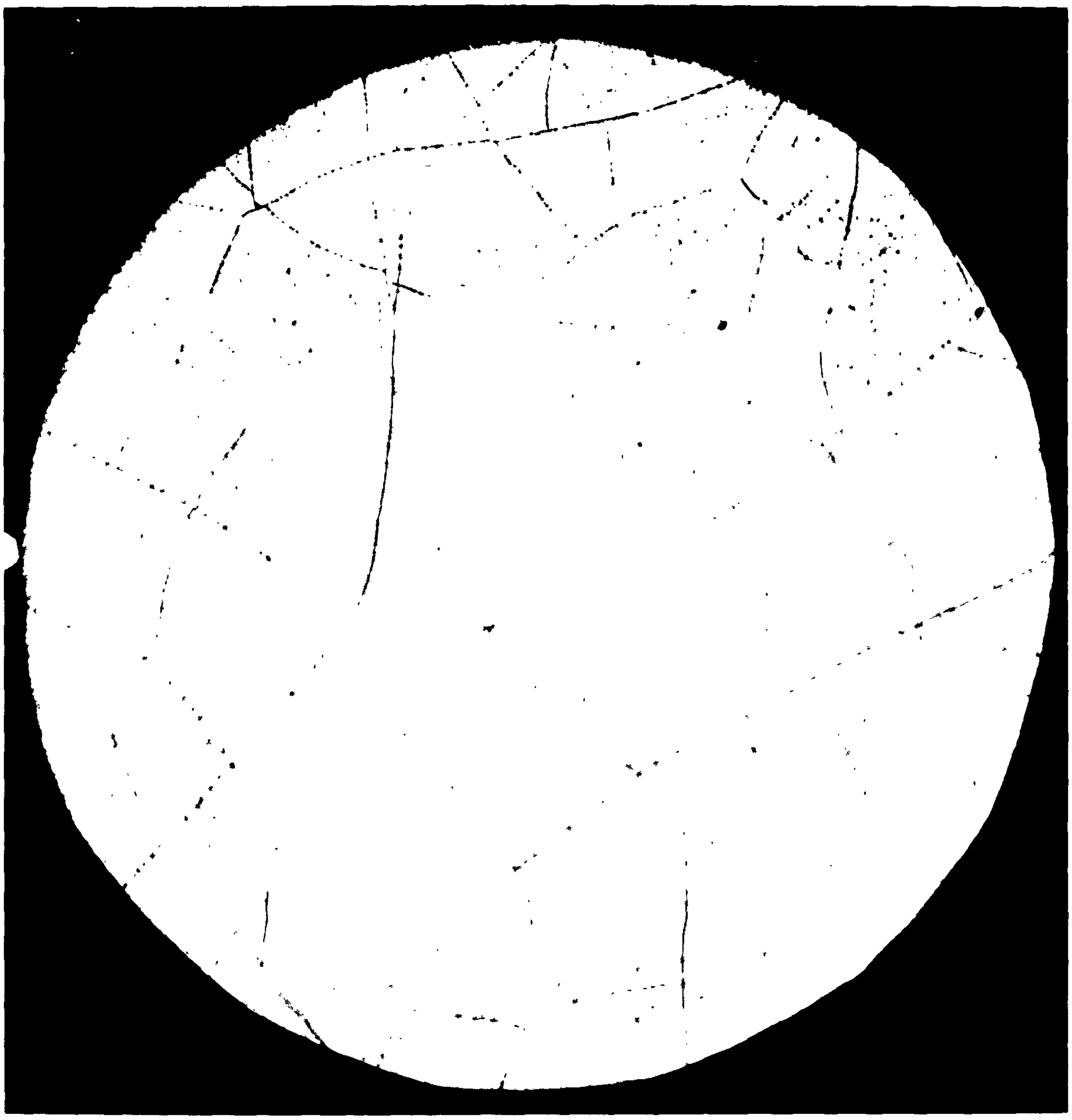

Figure 6 - Surface of SM-1 Seal Shaft Chromium Plate Showing Inherent Crack Pattern at 250 Diameters. This Crack Pattern Indicates by Linear Analysis a Pattern of 330 Cracks per Inch. (250X)

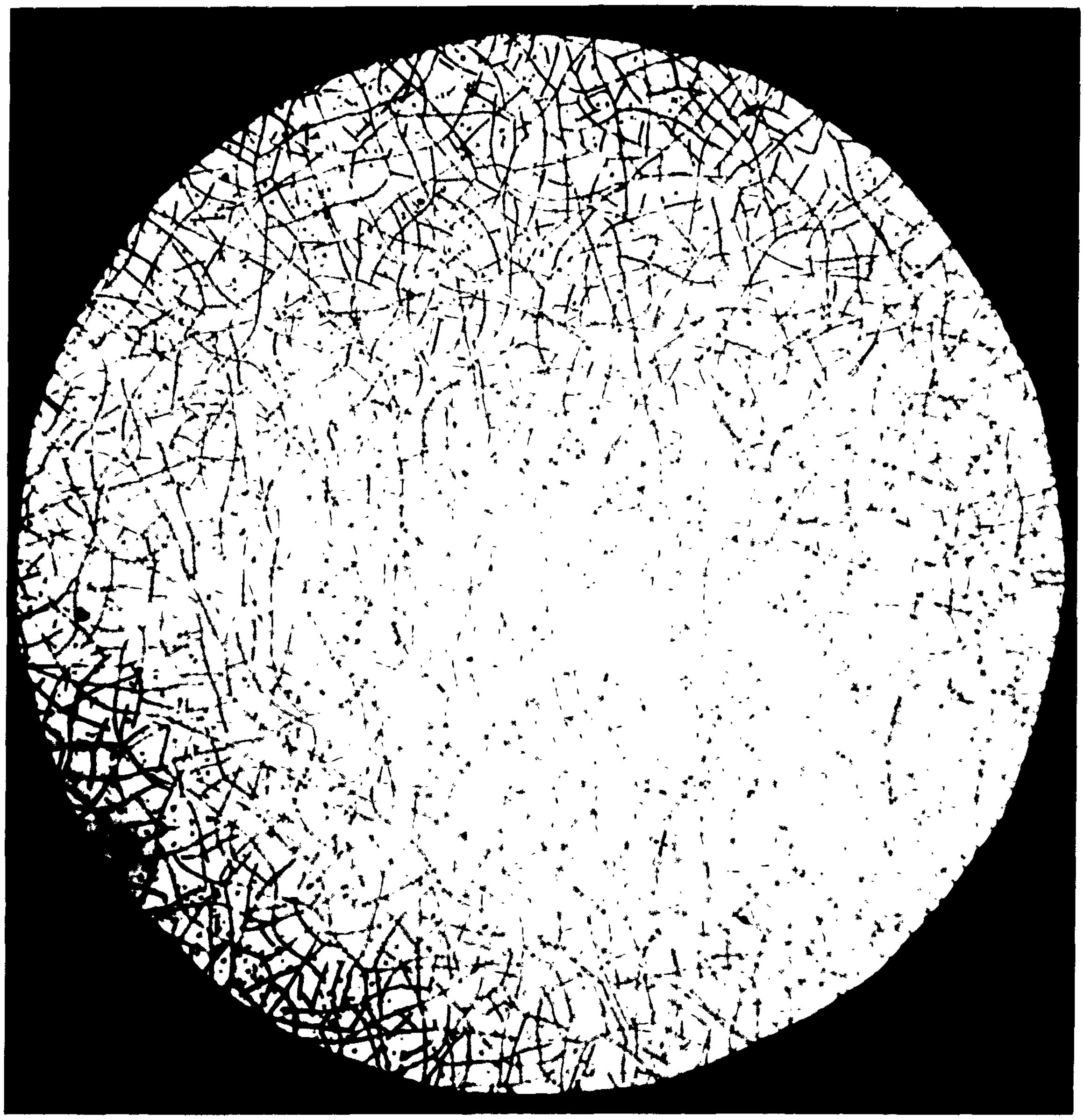

Figure 7 - Surface of Satisfactory Chromium Plate Showing an Inherent Crack Pattern of 2750 Cracks per Inch. (250X)

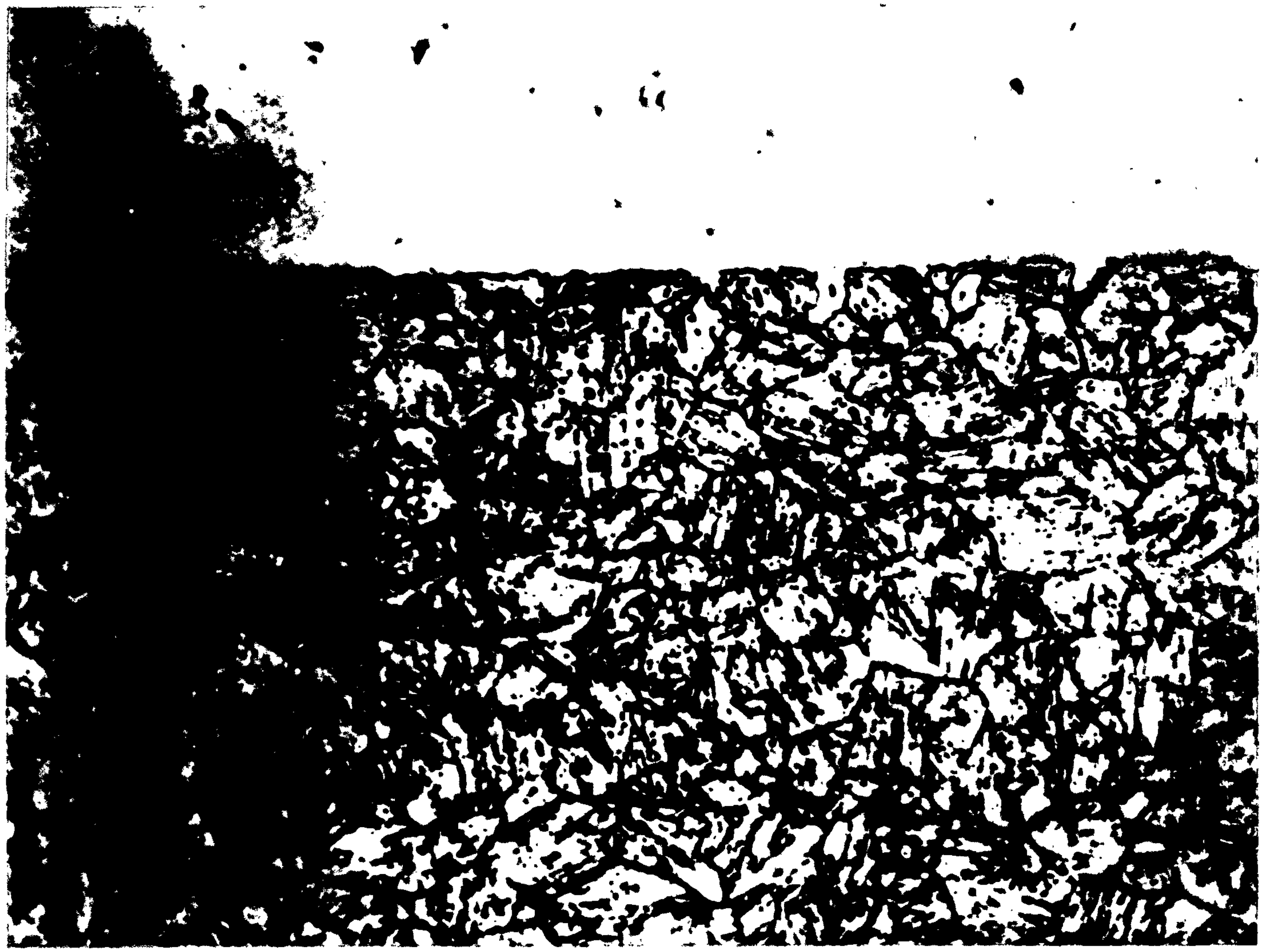

Figure 8 - A Longitudinal Section of Satisfactory Chromium Plate Showing the Absence of Non-metallic Intermediate Layer Between Base Metal and Plate Layer (1000X)

5.3.3 Conclusions

(1) The change noted on the K-Monel diaphragms are due to normal wear.

(2) The changes observed on the stellite seal rings are due to normal wear possibly accelerated in some instances by corrosion products.

(3) The worst pitting in each case occurred on the downstream end of the seal area, which is a logical place for pressure drop and cavitation in the seal assembly to contribute to erosion.

(4) Based upon available evidence from this examination, the most likely cause of the removal of the chromium plate,in addition to erosion,was the presence of non-metallic inclusions in the chromium plate.

(5) Comparison with a recently plated seal shaft showed the chromium plating to be of inferior quality in actual hardness, in indicated residual stress and in the presence of excessive non-metallic particles.

(6) The presence of a thin continuous non-metallic layer between the 17-4 PH material and the chromium indicate inadequate preplating cleaning, and may have contributed to the complete removal of chromium from the base metal in one local area.

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